Chapter 7. Special Studies

Dissolved Oxygen Monitoring in the Stockton Ship Channel

As part of a series of special studies authorized under the Environmental Monitoring Program, dissolved oxygen (DO) levels were monitored in the Stockton Ship Channel (Channel) from Prisoner's Point in the central Delta to the Stockton Turning Basin (Basin). This study was initiated to gain more information about periodic drops in DO levels that occur in the central and eastern portions of this Channel during the late summer and early fall. Dissolved oxygen levels reported within these regions from 1997 to 2000 were characterized by frequent occurrences of DO levels of ≤ 5.0 mg/L, which, in the context of this study, is defined as DO sag[1] (DO sag). Several factors are assumed to contribute to DO sags within the Channel. These factors include: low San Joaquin River inflows, warm water temperatures, high biochemical oxygen demand (BOD), reduced tidal circulation, and intermittent reverse flow conditions in the San Joaquin River past Stockton.

Because low DO levels can adversely impact fisheries and other beneficial uses of the waters within the upper San Francisco Estuary (Estuary), the State Water Resources Control Board (SWRCB) has established specific water quality objectives to protect these uses. Within the Channel, two separate DO objectives are mandated. From September through November, a DO objective of 6.0 mg/L has been established specifically for the eastern Channel (in the lower San Joaquin River between Stockton and Turner Cut) to protect fall-run Chinook salmon (SWRCB 1995). From December through August within the eastern Channel, and year round for the remainder of the Delta region, a DO objective of 5.0 mg/L has been established in the Basin Plan of the Central Valley Regional Water Quality Control Board (RWQCB 1998).

To alleviate the occurrence of low DO levels in the Channel, a rock barrier can be installed at the head of the Old River (Barrier) when warranted by the Department of Water Resources (DWR). This Barrier is designed to increase net flows in San Joaquin River past Stockton and minimize the occurrence of low DO levels in the channel. The Barrier is usually installed when average daily San Joaquin River flows past Vernalis are projected to be approximately 2000 cfs or less. The Barrier was not installed in 1997, 1998, or 1999. In 2000, however, the Barrier was installed on October 7 because fall flows past Vernalis were projected to be lower than 2,000 cfs.

Methods

DO levels in the Channel were monitored by vessel during the late summer and early fall. During each of the monitoring runs, 14 sites were sampled biweekly from Prisoner's Point (Station 1) in the central Delta to the Stockton Turning Basin (Station 14) at the terminus of the Channel (Figure 7-1). Discrete samples were taken from the top (1 meter from surface) and bottom (1 meter from bottom) of the water column at each site at ebb slack tide. These samples were analyzed for DO concentrations and temperature. Top DO samples were analyzed with the modified Winkler titration method (APHA 1998). Bottom DO samples were measured using either a YSI polarographic electrode (Model No. 5739) with a Seabird CTD 911+ datalogger, or with a YSI 6600 sonde equipped with a Model No. 6562 DO sensor. Water temperatures for top and bottom were measured using either a YSI 6600 sonde equipped with a Model No. 6560 thermistor temperature probe, or a Seabird SBE3 temperature probe.

[1] For the purpose of this study, a "DO depression" is defined as the occurrence of DO levels ≥ 5.0 mg/L and ≤ 6.0 mg/L, and a "DO sag" is defined as DO levels of ≤ 5.0 mg/L.

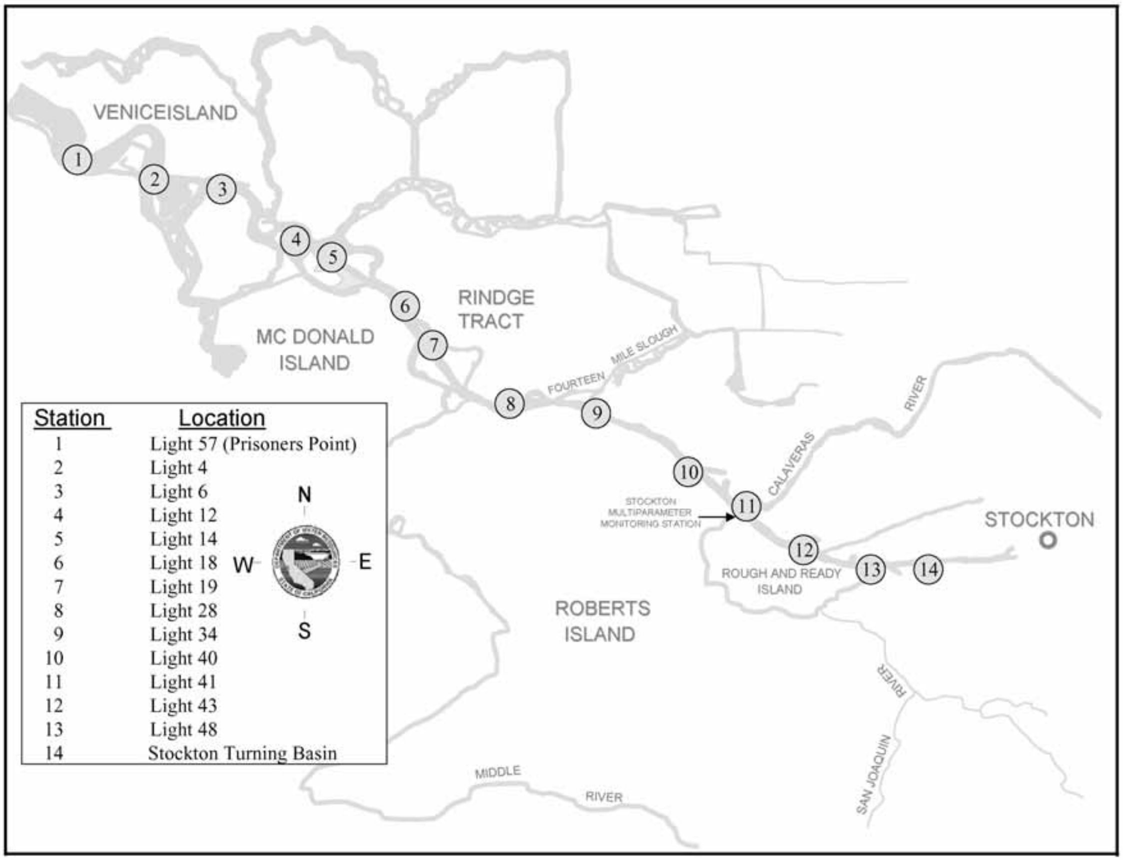

Figure 7-1 Map of dissolved oxygen monitoring stations

Flow data for the San Joaquin River at Vernalis and Stockton were obtained from continuous monitoring stations compiled by DWR's Division of Operations and Maintenance[2] and by USGS[3]. Flows past Vernalis were down-channel throughout the year and are reported as an average daily flow rate. Flow rates in the San Joaquin River at Stockton are heavily influenced by tidal action, with daily ebb and flood tidal flows of 3,000 cfs or greater in either direction. To calculate net daily flows, the tidal pulse is removed from the USGS 15-minute flow data with a Butterworth filter[4] to yield net daily flow. Because of low flows at Vernalis, local agricultural diversions, and export pumping, net daily flows at Stockton can sometimes be reversed, or up-channel, in which case the average daily flow rate is reported as a negative value.

Results and Discussion

Measured flows in the San Joaquin River at Vernalis and Stockton are summarized by year in Table 7-1, along with measured water temperature conditions and minimum observed DO levels for the critical August through October period. Based on late summer and early fall DO findings and projected fall flows, DWR decides whether to have the Old River Barrier constructed. When deemed necessary the Barrier is usually constructed in September.

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[2] Division of Operations and Maintenance, Department of Water Resources, 1416 Ninth Street, Room 620, Sacramento, CA 95814.

[3] Station information: Station SJR at Vernalis, RSAN112

[4] USGS uses a Butterworth bandpass filter to remove frequencies (tidal cycles) from 15-minute flow data, that occur on less than a 30 hour period. The resulting 15-minute time-series is then averaged to provide a single daily value which represents net river flow exclusive of tidal cycles.

Table 7-1 Summary of flow and water quality conditions in the San Joaquin River during the late summer and fall, 1997-2000

Year	Vernalis Avg. Daily Flow Aug.-Nov. (cfs)	Stockton Range of Flows Aug.-Nov. (cfs)	Reverse Flow at Stockton?	Water Temp. Aug.-Sept. (°C)	Water Temp. Oct.-Nov. (°C)[1]	Minimum DO Aug.-Nov. (mg/L)	Barrier at Old River?
1997	2,089	–466 to +188	Present	22.0 – 27.8	15.6 – 24.3	2.6	No
1998	5,042	1,070 to 2,011	Not Present	21.9 – 28.0	16.3–18.8*	5.0	No
1999	2,139	-392 to +352	Present	21.0 – 26.5	13.4 – 21.9	3.2	Yes
2000	2,413	–401 to +626	Present	21.8 – 27.1	12.7 – 19.4	4.5	No

[1] By late fall, water temperatures within the Stockton Ship Channel had dropped considerably from the late summer measurements. By the end of monitoring (usually in November) the temperatures within the Channel were 15 °C or less. Monitoring in 1998 ended on October 20.

During the 1997 through 2000 calendar study period[5], water years 1997 and 1998 were classified as "Wet", and water years 1999 and 2000 were classified as "Above Average", according to the San Joaquin Valley 60-20-20-Water Year Hydrological Classification Index[6]. Although the fall San Joaquin River flows past Vernalis were relatively high for all years, the DO conditions within the Channel differed considerably between years. The late summer and early fall DO conditions for each year are described in the remainder of this text.

Calendar Year 1997

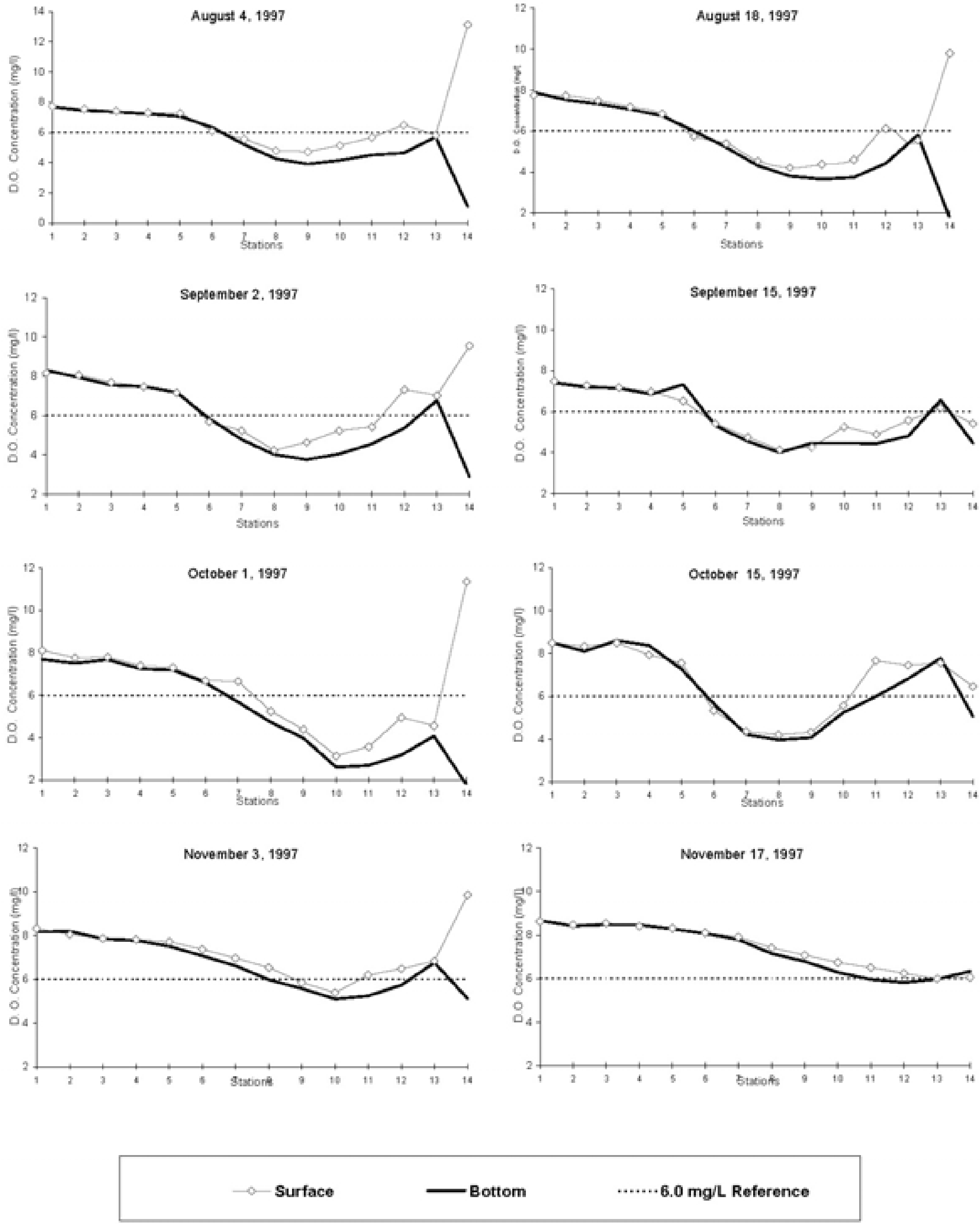
Calendar year1997 was a wet year with moderate San Joaquin River fall flows past Vernalis averaging 2,089 cfs (Table 7-1). The average daily flows in the San Joaquin River past Vernalis approached 2,000 cfs in August and September and exceeded 2,000 cfs in October and November. Because of these relatively high average daily flows and the potential for overtopping, bank erosion, and October reservoir drawdown releases, the Old River Barrier was not installed in the fall of 1997. In spite of the relatively high flows in the San Joaquin River past Vernalis, average daily flows past Stockton ranged from -466 cfs to +198 cfs from August through September (Table 7-1). Reverse flows past Stockton continued until early October when flood-control related reservoir releases within the drainage basin of the San Joaquin River were initiated.

A DO sag developed in the eastern Channel immediately west of the Rough and Ready Island area (Stations 8 through 13) in August, and persisted through early October (Figure 7-2). This DO sag was coincident with a period of warm water temperatures (22-27 °C), and reverse flow conditions past Stockton.

Improved flow conditions in the San Joaquin River ended reverse flow conditions at Stockton on October 10. By October 15 the DO sag had lessened and had moved downstream. By mid-November the DO sag was eliminated.

[5] Because a water year ends on September 30, which is midway through the typical August through November study period, the findings of the fall DO special studies are discussed primarily using calendar years to eliminate the need to use two water years to describe one fall study period. However, hydrologic conditions within the drainage basin of the San Joaquin River influence inflows to the Stockton Ship Channel, and water years will be used when discussing these conditions.

[6] The San Joaquin Valley 60-20-20-Water Year Hydrological Classification Index is used because inflows to the Stockton Ship Channel occur predominantly through the San Joaquin River.



*Note changes in scale

Figure 7-2 Dissolved oxygen concentrations in the Stockton Ship Channel in 1997

Calendar Year 1998

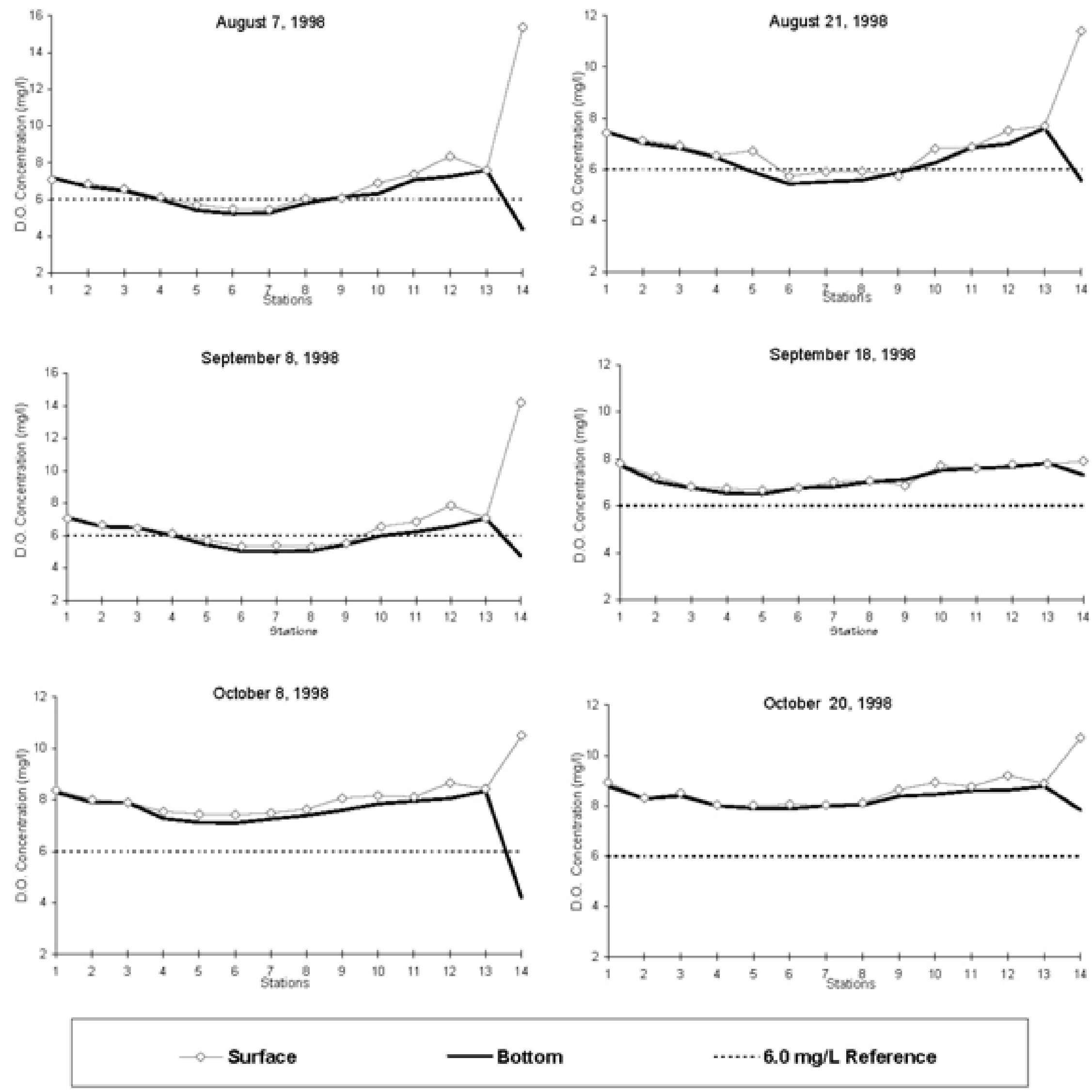
Calendar year 1998 was a wet year with high San Joaquin River fall flows past Vernalis averaging 5042 cfs (Table 7-1). Average daily flows past Stockton ranged from 1,020 to 2,011 cfs. No reverse flows were recorded during the year. Because of the exceptionally high flows at Vernalis and the absence of reverse flow conditions at Stockton, the Barrier at Old River was not constructed.

In spite of the exceptionally high San Joaquin River inflows into the eastern Channel, a DO depression, an area in the channel where DO levels are greater than or equal to 5.0 mg/L and less than or equal to 6.0 mg/L, occurred in the central Channel from Columbia Cut (Station 5) to Fourteen Mile Slough (Station 9) in August and early September (Figure 7-3). This area of depression was considerably west of the Rough and Ready Island area in the eastern Channel where the sag area has historically occurred. By October 20, 1998, DO levels throughout the Channel recovered to levels > 8.0 mg/L due, in part, to cooler water temperatures (15-18 °C in October) and sustained high San Joaquin River inflows to the Channel.

Calendar Year 1999

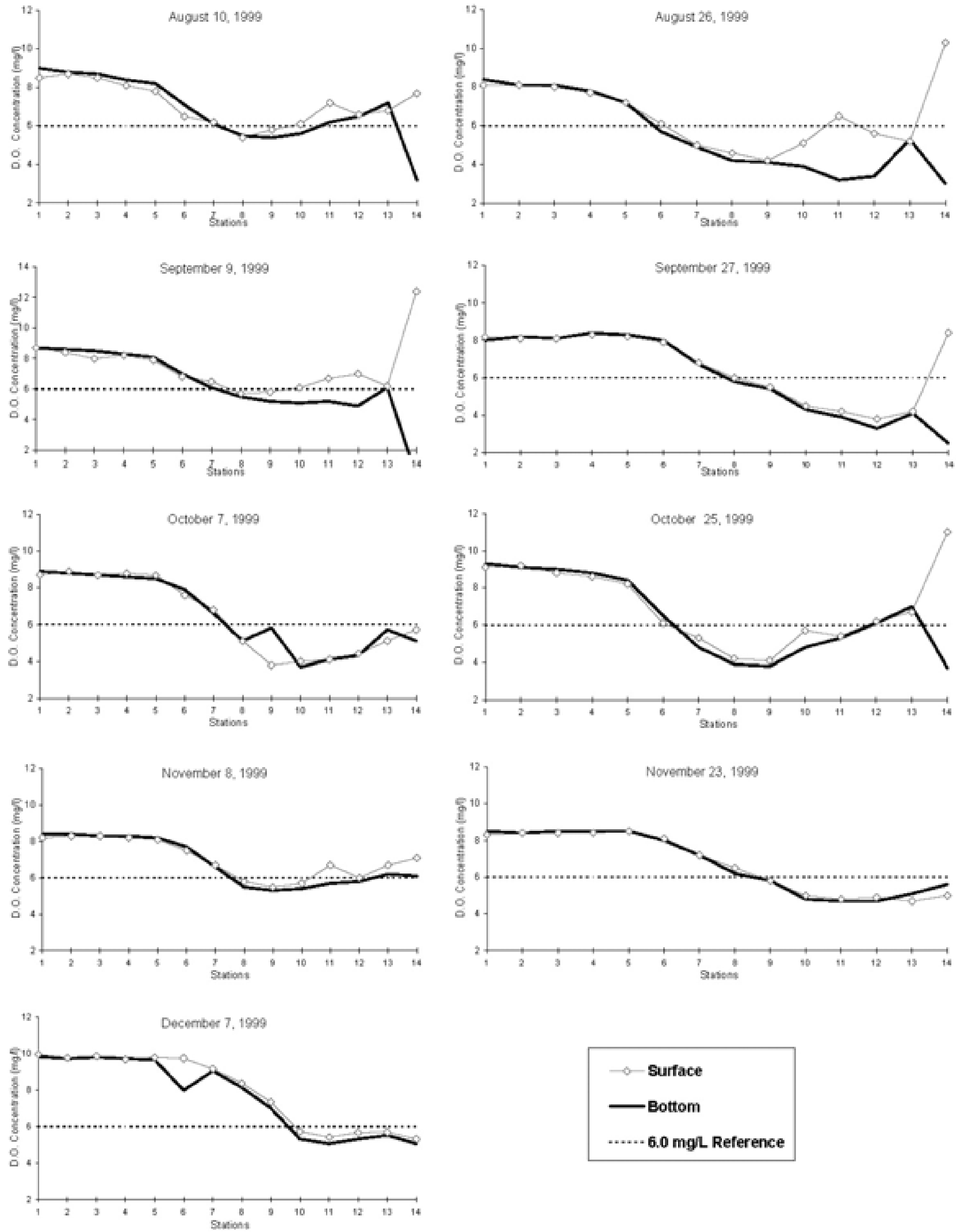
Calendar year 1999 was an above average water year with moderate San Joaquin River fall flows. The average daily flows in the San Joaquin River past Vernalis were 2,139 cfs (Table 7-1). Because of the relatively high average daily flows, and concern over possible bank erosion and overtopping, the Old River Barrier was not installed. In spite of the high average daily flows in the San Joaquin River past Vernalis, average daily flows past Stockton ranged from -392 cfs to +352 cfs from August through November. These reverse flows continued until early December when reservoir releases within the drainage basin of the San Joaquin River were initiated.

In November and December of 1999, field crews observed extensive dredging in the central and eastern Channel. In addition, aerators maintained by the Army Corps of Engineers near the eastern end of Rough and Ready Island (Station 13) were not operating during the dredging operations, as required. The lack of aeration and potential increase in BOD may have contributed to the persistence of DO levels of $\leq$ 5.0 mg/L measured within the central and eastern Channel in 1999 through late fall (Figure 7-4). The 1999 DO sag was the longest lasting of the four-year monitoring period. Unlike previous years, DO concentrations did not recover to levels greater than 6.0 mg/L in the central and eastern Channel in the late fall, despite slightly higher inflow and markedly cooler water temperatures (10 -17 °C in November and December).



*Note changes in scale

Figure 7-3 Dissolved oxygen concentrations in the Stockton Ship Channel in 1998



*Note changes in scale

Figure 7-4 Dissolved oxygen concentrations in the Stockton Ship Channel in 1999

Calendar Year 2000

Calendar year 2000 was an above average water year, with moderate late summer San Joaquin River flows past Vernalis averaging 2,415 cfs (Figure 7-5). Because late summer San Joaquin River flows past Vernalis were relatively low, and fall flows were not projected to be sufficient to alleviate DO concerns within the eastern Channel, DWR installed the Old River Barrier on October 7. Although average daily flows in the San Joaquin River past Vernalis increased in October, the installation of the Barrier was not sufficient to eliminate reverse flow conditions in the San Joaquin River past Stockton. Average daily flows past Stockton ranged from -401 cfs to +626 cfs from August through October (Figure 7-5).

A DO sag was detected in the central portion of the Channel on August 14, a period when water temperatures were warmest and San Joaquin inflows were lowest (Figure 7-5). Although DO levels improved to 6.0 mg/L or greater in late August and early September, a DO depression developed within the Channel by September 26. This depression also coincided with warm water temperatures (21-27 °C) and sustained reverse flow conditions past Stockton. Dissolved oxygen conditions improved in early October, and were ≥ 8.0 mg/L throughout the Channel by October 26. These high levels were sustained in November, and the Old River Barrier was removed on December 8.

Turning Basin

Exceptionally high surface and low bottom DO levels were periodically measured in the Stockton Turning Basin in the fall during all four years of the study. Surface DO levels ranged from 7.7 to 17.0 mg/L, and bottom DO levels ranged from 0.3 to 5.6 mg/L (Figures 7-2 through 7-5).

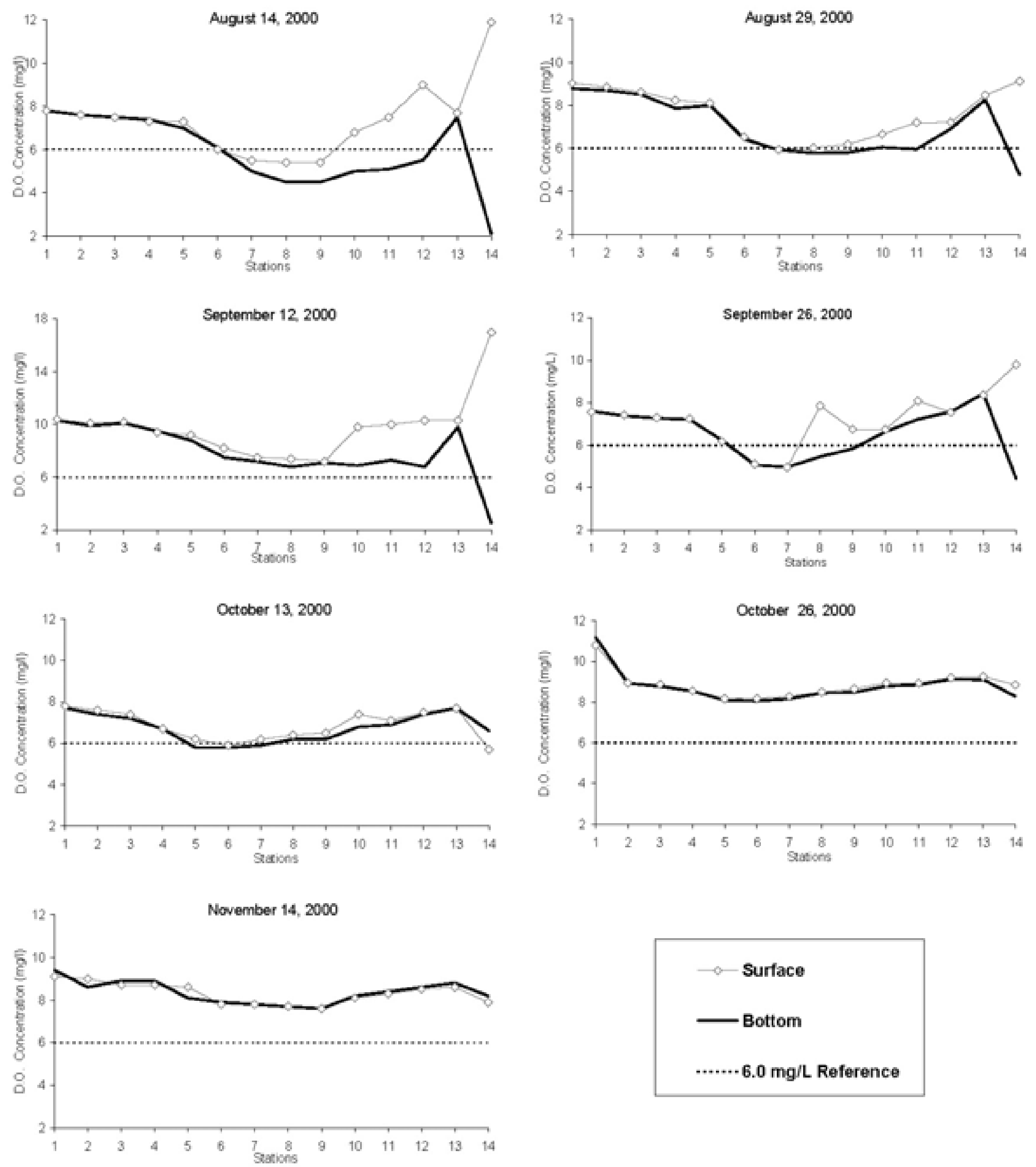
The highly stratified DO conditions periodically detected appear to be the result of localized biological and water quality conditions occurring within the Basin. The Basin is at the eastern dead-end terminus of the Ship Channel. The Basin has lower tidal activity and water circulation, and increased residence times, as compared with the downstream Channel. As a result, water quality and biological conditions within the Basin historically differ from those within the main downstream Channel.

The Basin also has periodic extensive late summer and fall algal blooms and die-offs. These algal blooms are composed primarily of cryptomonads, diatoms, flagellates, blue green algae, and green algae. When conditions are right, these blooms can result in highly vertically stratified DO levels. At the surface, high algal production produces supersaturated DO levels. At the bottom, dead or dying algae contribute to high oxygen demand and can deplete DO levels to near zero. Water quality conditions in the Basin are further influenced by BOD loadings in the area from regulated discharges into the San Joaquin River, and from recreational activities adjacent to the Basin.

Summary

Monitoring of DO conditions in the Stockton Channel from 1997 to 2000 showed that DO levels regularly dropped below the State established water quality objectives. Although this special study was not designed to determine the specific cause of these DO sags, it appears that specific hydrologic conditions, combined with changes in biochemical oxygen demand, algal production, and water temperature, affect DO levels within the channel.

Because hydrologic measurements are available for use with this study, it is possible to make preliminary observations between recorded DO levels and Channel hydrology. In particular, DO levels dropped below 5 mg/L in the Channel primarily when reverse flows occurred (Table 7-1). In addition, low DO levels appeared to be associated with low flow conditions (Table 7-1).



*Note changes in scale

Figure 7-5 Dissolved oxygen concentrations in the Stockton Ship Channel in 2000

Algal Bloom Surveys

Introduction

Algal blooms are a natural and regularly occurring phenomenon within the upper San Francisco Estuary. The Compliance Monitoring Program has conducted special studies over the years to identify the causative bloom organisms and to document the extent and intensity of those blooms. These studies were conducted in response to mandated Compliance Monitoring and in response to the bloom's potential impact to the State Water Project (SWP) operations and the upper San Francisco Estuary. This chapter briefly describes algal bloom surveys conducted during the 1997 through 2000 calendar year period.

The Upper San Francisco Estuary contains more than 600 species of phytoplankton, many of which can cause water-discoloring blooms when rapid growth of a phytoplankton species is triggered by suitable conditions. A number of environmental factors influence the growth of phytoplankton, including nutrient levels, photoperiod, light intensity, water temperature, pH, salinity, turbidity, flow rates, and predation. Generally, algal blooms occur in the Estuary when nutrient availability is sufficient, predation is low, and factors essential for phytoplankton growth such as light and water temperature are within the appropriate ranges. Blooms generally occur in the late winter and spring when nutrient levels are at, or near, their maximum; water temperature and light levels have increased to suitable levels for algal growth; and inflows have dropped sufficiently to permit water residence times within the Estuary sufficient for rapid algal growth.

Blooms in most estuaries can be identified visually by the appearance of free-floating algae or the distinct coloration of surface water due to the presence of algae. A bloom can also be defined by the presence of highly elevated surface chlorophyll *a* concentrations. Within the upper San Francisco Estuary, the blooms detected typically showed both characteristics. Figure 7-6 shows the location of the major blooms detected within the estuary during the study period.

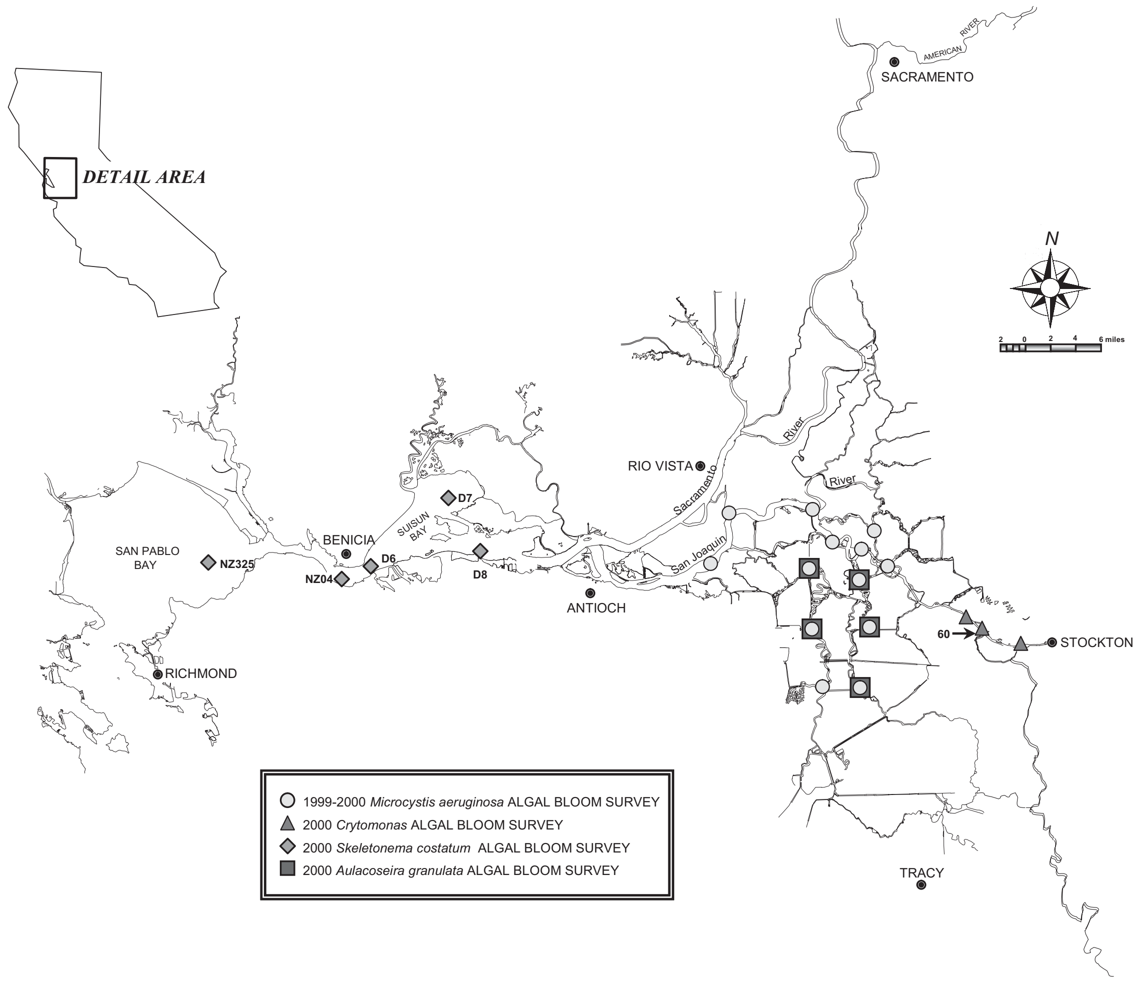


Figure 7-6 Map of algal blooms surveyed during 1997-2000

Methods

Monitoring for algal blooms is incorporated within the protocols for regular monthly mandated monitoring aboard the research vessel *San Carlos*. The presence of blooms is monitored visually or by continuous fluorometric readings while the vessel is moving or at fixed predetermined sampling stations. Water samples are pumped from a 1-meter depth through an onboard continuous monitoring instrument (Sea Bird Electronics/31 unit), which records values for water temperature, DO, and specific conductance. A flow-through Turner Designs Model 10-AU digital field fluorometer and nephelometer measure chlorophyll fluorescence and nephelometric turbidity values, respectively. When a bloom is observed, discrete samples are collected for measurement of extracted chlorophyll *a* and phytoplankton identification by Bryte Laboratory.

Emergency follow-up studies are conducted when a bloom organism may cause taste and odor problems and clog filters for municipal water supplies. These studies sample at 15 stations throughout the central and southern Delta (the area leading to Clifton Court Forebay and the Harvey O. Banks Pumping Plant). In addition, DWR's Delta Field Division and the Contra Costa Water District are notified so that staff can alter project operations or adjust water treatment procedures as necessary to accommodate for the presence of the organism within the Estuary.

Results

Approximately four algal blooms were observed and monitored during the period of this study. The causative organisms were identified as belonging to one of four primary species in the following genera: *Microcystis, Cryptomonas, Skeletonema,* and *Aulacoseria.*

During the late winter and early spring of 2000 (March and April), a bloom of the filamentous diatom, *Skeletonema costatum,* was detected. Historically, most of the blooms in San Pablo and Suisun bays have been *S. costatum* (Cloern and Cheng 1981). This bloom was initially detected in a localized area in mid-March near Station NZ325 (Light 11-San Pablo Bay) (Figure 7-6). During subsequent follow-up surveys in mid-April, the bloom had expanded easterly to include Suisun Bay near Station D8. Growth rates for this diatom are governed primarily by light availability, salinity, and temperature (Cloern 1979; Cloern and Cheng 1981).

In early September 2000, the bloom-forming diatom with filter clogging potential, *Aulacoseira* (formerly *Melosira*) *granulata*, was detected. The bloom formed a thick filamentous mat that fouled the plankton net used in sample collection. *A. granulata* was identified in five phytoplankton samples collected at stations in the central and southern Delta. This species commonly occurs in the southern Delta during summer when salinity is high from discharge of agricultural return water and when longer residence times have increased water temperature (Lehman 1996).

In the eastern Delta, a brief and moderately intense phytoplankton bloom occurred in the Stockton Ship Channel in late May 2000. The bloom was near the multi-parameter recording station (Station 70) in the San Joaquin River at Burns Cutoff, near the Rough and Ready Island. Algal production rates in this area, in the late spring and early summer, are typically influenced by increased light intensity, warmer water temperatures and lower San Joaquin River inflows (Lehman 1996). The high productivity characteristic of the Stockton Turning Basin and Yacht Harbor may have also contributed to the establishment of the bloom in the San Joaquin River. At the end of May 2000, the bloom extended from the San Joaquin River at Buckley Cove to the Stockton Yacht Harbor at the extreme eastern end of the Stockton Ship Channel. The bloom consisted of mixed phytoplankton species, with *Cryptomonas* being the most dominant alga. Other algae present included *Thalassiosira eccentrica*, *Aphanizomenon flos-aquae*, *Cosinodiscus*, and flagellated green algae. Cryptophytes and flagellate groups are most abundant in dry water-years and tolerate higher water temperatures (Lehman 1996), which was characteristic of climatic conditions during this bloom formation.

The central and southern Delta taken as a whole is a region where significant bloom activities occurred during the study period. Water quality in this area is typically influenced by low summer and fall stream inflow. The southern Delta, in particular, has longer residence times than regions adjoining the Sacramento and San Joaquin rivers, and is characterized by high phytoplankton biomass levels (Lehman 1996). Historically, most of the blooms that occurred in this area were primarily composed of diatoms, but the percentage of diatoms relative to other algal groups in this area has decreased during the last two decades. This decrease was accompanied by an increase in the percentage density of green algae, blue-green algae, and flagellates, as well as an increase in total algal bio-volume (Lehman 1996, 2000). Although the magnitude of the blooms varied in this portion of the Estuary, the blue-green alga, *Microsystis aeruginosa,* was persistent from September through mid-November 1999, and during July, August, and September 2000.

Microsystis aeruginosa, notorious for causing taste and odor problems, was observed as green, irregularly shaped flakes approximately one-quarter to three inches in diameter floating on or near the water surface. Since *M. aeruginosa* is also known to produce toxins, called microcystins, that may adversely affect water supply and water treatment facilities, special studies were conducted in 1999 and 2000 to determine the extent and intensity of this bloom. Phytoplankton samples and field observations conducted during these algal surveys confirmed the presence *M. aeruginosa* at 15 stations in the central and southern Upper Estuary. Blue-green alga blooms in freshwater lakes, in stock ponds, and in lagoons have been associated with low flows, warm water temperatures, increased water clarity, and high nutrient inputs. The duplication of these conditions during the exceptionally warm and dry fall of 1999 and 2000 may have stimulated these blooms.

Summary

The results of the algal bloom special study program have provided important information to supplement the long-term mandated program to monitor water quality conditions in the upper San Francisco Estuary. The special study program showed that periodic algal bloom activity is located primarily in the central and southern Delta, and that Delta-wide blooms were dominated by *Microcystis, Cryptomonas, Skeletonema, and Aulacoseria.*

Water Right Decision 1641 has modified the mandated monitoring program to emphasize monthly rather than bi-weekly water quality monitoring. Because algal monitoring is not continuous, blooms may not be readily detected unless they occur during a monthly water quality monitoring run. Algal blooms of short duration or blooms that occur outside of regular monitoring areas may not also be detected either. To address this issue, dedicated algal surveys that are timed and located based on plankton biology are being developed to further clarify the biological, chemical, and physical processes leading to the initiation and development of algal blooms in the upper San Francisco Estuary.